U.S. DEPARTMENT OF COMMERCE
National Technical Information Service

PB-270 852

Dynamometer Distance

Environmental Protection Agency, Ann Arbor, Mich

Jul 75

EPA 75-1

PB 270 852

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by

Thomas Barlok

July 1975

Standard Development and Support Branch
Emission Control Technology Division
Office of Mobile Source Air Pollution Control
Office of Air and Waste Management
Ann Arbor, Michigan 48105

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NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

BIBLIOGRAPHIC DATA SHEET	1. Report No.	2.	3. Recipient's Accession No.
4. Title and Subtitle: Dynamometer Distance			5. Report Date: July 1975
7. Author(s): Thomas Barich			8. Performing Organization Rept. No. LDTP 75-4
9. Performing Organization Name and Address: Standards Development and Support Branch Emission Control Technology Division U.S. Environmental Protection Agency Ann Arbor, Michigan 48105			10. Project/Task/Work Unit No.
			11. Contract/Grant No.
12. Sponsoring Organization Name and Address: Same as above			13. Type of Report & Period Covered: Technical Support Report
			14.

15. Supplementary Notes

16. Abstracts: In addition to mass emissions, fuel economy is being calculated under the assumption that the distance travelled during the Federal test cycle is 7.5 miles. It has been proposed that the actual distance travelled on the dynamometer be measured and used in the mass emissions and fuel economy calculations. In order to be able to use the total distance travelled in the calculations, a means of accurately measuring the distance and a change in the Federal Register are required. Recomendations: the total distance travelled on the dynamometer be measured and that the distances travelled during each phase of the Urban Dynamometer Driving Schedule exhaust test be used to calculate the mass emissions; the total distance travelled during the Highway Fuel Economy Test should be measured and used in the calculation of fuel economy.

17. Key Words and Document Analysis. 17a. Descriptors

Air pollution
Motor vehicles
Fuel consumption
Exhaust gases
Dynamometers
Tests
Measurement

17b. Identifiers/Open-Ended Terms

Fuel economy
Test procedures
Measurement methods

17c. COSATI Field/Group

18. Availability Statement: Release Unlimited	19. Security Class (This Report): UNCLASSIFIED	21. No. of Pages: 9
	20. Security Class (This Page): UNCLASSIFIED	22. Price: PCA04 / MF1

FORM NTIS-35 (REV. 10-73) ENDORSED BY ANSI AND UNESCO. THIS FORM MAY BE REPRODUCED

Dynamometer Distance

The current means of calculating mass emissions in grams per mile assumes that the distance travelled during the Federal test cycle is 7.5 miles. With the current tolerances on the FTP driving trace, the total distance travelled during a test may be significantly higher or lower than 7.5 miles. Now that fuel economy is also being calculated and it is also based on 7.5 miles travelled, it has been proposed that the actual distance travelled on the dynamometer be measured and used in the mass emission and fuel economy calculation. In order to be able to use the total distance travelled in the calculations, a means of accurately measuring the distance and a change in the Federal Register are required.

The 7.5 mile value is the distance a vehicle would travel during the Federal Test Procedure cycle if it were to follow the trace exactly. However, the tolerances on the driving trace allow a vehicle to travel 2 mph higher than the highest point on the trace within 1 second of a given time, and 2 mph lower than the lowest point on the trace within 1 second of a given time. Tolerances are necessary since a driver cannot physically drive the trace exactly.

The tolerances make it possible for the vehicle to travel a distance which is more or less than the 7.5 miles used in the calculations. If the vehicle were to travel at the upper tolerance throughout the entire driving schedule, it would travel 8.55 miles or 14% farther than the 7.5 miles used in the calculations. If the vehicle were to travel at the lower tolerance throughout the entire driving schedule, it would travel 6.52 miles or a 13% shorter distance than the 7.5 miles used in the calculations. These percentages would become the percent errors possible due to distance in the mass emission and fuel economy calculations.

Although the above mentioned tolerances are theoretically possible, it is important to examine the magnitude of the errors experienced in actual testing. Data made available by some of the auto manufacturers make this evaluation possible. Figure 1 shows a frequency distribution of total miles travelled during Phase 1 of the Federal Test Procedure exhaust test in testing conducted at General Motors (1). It can be seen from this figure that approximately 95% of the test data lie in the range of 3.78 to 3.89 miles travelled. Since the nominal distance travelled is 3.859 miles, the maximum error in miles travelled 95% of the time would be 2.0% of the nominal distance based on the following calculation:

$$\text{maximum error} = \frac{3.859 - 3.78}{3.859} \times 100 = 2.0\%$$

This error could be translated to a 2.0% error in fuel economy. Whether this result is also true for the total exhaust test cycle cannot be determined from these data, but data supplied by Ford Motor Company do give some indication of the errors that might exist for the entire test cycle. Table 1 is a summary of the tests conducted at Ford (2) for the urban dynamometer driving cycle. The data directly relate the variability of fuel economy measurements when the actual distance and nominal distance are used. The data show that approximately a 1.2% decrease in test variability would be realized by using the actual distance travelled instead of the nominal distance travelled. In addition to these data Toyota (3) reported that their tests indicated that all data for distance travelled were within ± 1% of the 11.1 mile nominal distance travelled during the entire Federal Test Procedure exhaust cycle, and Volkswagen (4) reported a deviation of ± 1/3 mile or ± 4% for highway driving cycle tests conducted.

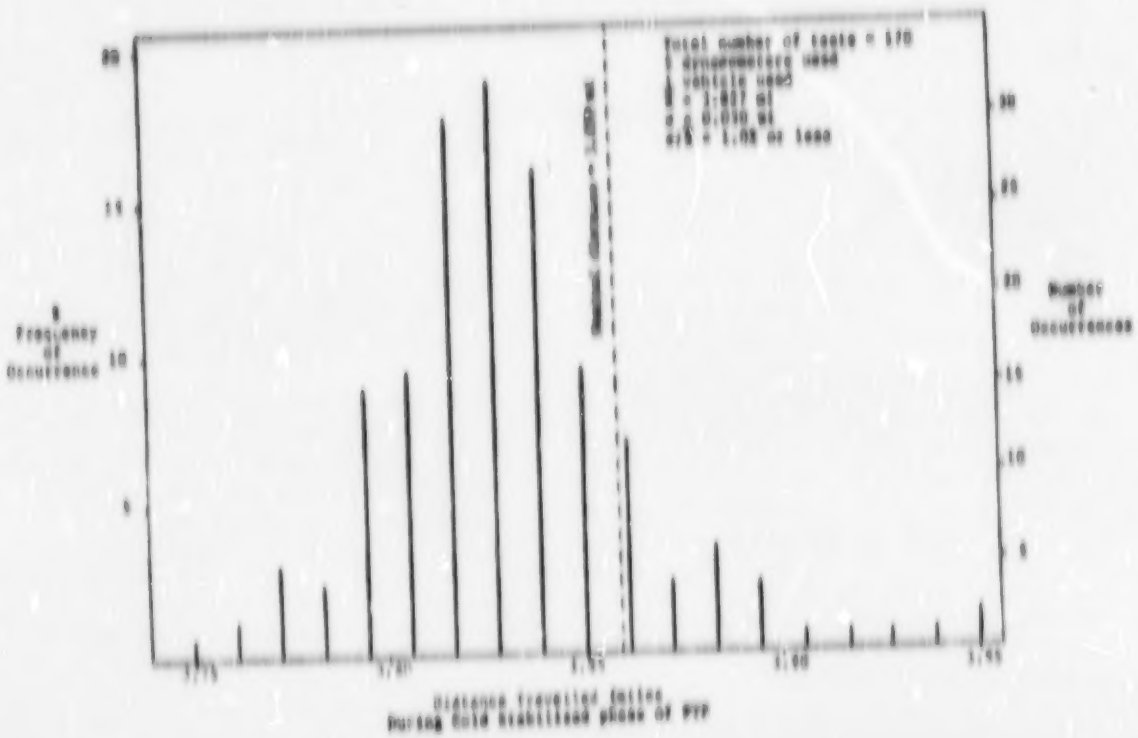

Figure 1. Frequency Distribution of miles travelled during the "stabilized phase of the 1975 FTP exhaust test

Fuel Economy/Distance Travelled Comparison

City Cycle	Actual Distance	Nominal Distance
Mean Consumption Gal/Mile	0.07987	0.07999
Consumption Variability SIGMA/MEAN	± 2.5%	± 3.74%
Harmonic Mean Fuel Economy mpg	12.52	12.50
Fuel Economy Variability SIGMA/H. MEAN	+ 2.6% - 2.4%	+ 3.9% - 3.6%

All of the data supplied by the manufacturers indicate that errors as large as those theoretically possible due to the tolerances on the trace do not in reality exist. The maximum error appears to be in the range of 3 to 4% of the nominal distance used in the calculation of mass emissions. This degree of error in the distance travelled would result in a 3 to 4% error in the Fuel Economy calculation. Somewhat larger errors may exist for tests conducted from one dynamometer to another due to inaccuracies in the speed calibrations from one dynamometer to another. The measurement of the distance travelled should be made directly from the rolls in order to eliminate these differences due to the dynamometer speed calibration.

Another source of error occurs when vehicles are tested that do not have sufficient power to achieve the acceleration rates or reach the maximum speeds required in the test cycle. Testing at EPA has shown instances where this condition existed and deviations from the nominal distance travelled were estimated to be as large as 1/2 mile or 6.7%. This condition may be of increasing concern in the future as smaller more economical vehicles are produced. Since such vehicles are allowed to operate at lower than specified speeds by the Federal Register, it is important that the distance travelled be measured and used in the computation of mass emissions and fuel economy so that higher fuel economy values are not reported than actually exist.

Currently the mass emissions of hydrocarbons, NOx and CO are based on a vehicle traveling 7.5 miles on the dynamometer. The equation from the Federal Register for calculating mass emissions is shown below.

$$Ywm = (0.43\ Yct + 0.57\ Yht + Ys)/7.5 \qquad \text{Eqn. I}$$

where

Ywm = Weighted mass emissions of each pollutant, i.e. HC, CO, or NOx, in grams per vehicle mile;

Yct = Mass emissions as calculated from the "transient" phase of the cold start test, in grams per test phase.

Yht = Mass emissions as calculated from the "transient" phase of the hot start test, in grams per test phase.

Ys = Mass emissions as calculated from the "stabilized" phase of the cold start test, in grams per test phase.

Fuel economy calculations are based on the mass emissions calculations and are therefore also based on a total distance of 7.5 miles. The fuel economy calculation is shown below.

$$mpg = \frac{2423}{.866\ (gpm\ HC) + .429\ (gpm\ CO) + .273\ (gpm\ CO_2)} \qquad \text{Eqn. II}$$

In the past the only calculation that was based on 7.5 miles was the mass emission calculation. That calculation produced a number that was compared to a standard to determine whether or not the vehicle passed or failed its emission test. It was assumed that the actual distance travelled would be reasonably close to 7.5 miles and thus there was no need for an accurate measurement. The fuel economy calculation on the other hand produces a number that is not meant to be compared with a standard but is used to compare that vehicle's fuel economy with the fuel economy of other vehicles. Since the level of fuel economy is an important selling feature of a car, the accuracy to which it is measured is important. The large percentage error that is possible due to differences in actual distance travelled can produce an unfair comparison between two vehicles.

Recommendations:

It is recommended that the total distance travelled on the dynamometer be measured and that the distances travelled during each phase of the Urban Dynamometer Driving Schedule exhaust test be used to calculate the mass emissions. In addition the total distance travelled during the Highway Fuel Economy Test should be measured and used in the calculation of fuel economy.

In order to implement the use of the measured distance travelled, a means of measuring that distance and appropriate changes (technical amendments) to the Federal Register are required. The distance measurement device should be able to deliver an accuracy of ± 0.5% and it should be capable of giving separate measurements of distance for the separate phases of the test cycle.

Two changes in the Federal Register would also be required. First, in §85.075-12, a provision would have to be made for recording the distance travelled during cold transient, stabilized, and hot transient phases of the test. Secondly, a change would be required in §85.075-26(a) to change the current method of calculation.

The current equation for calculating mass emissions on a grams/mile basis (Eqn I) can be rearranged and expressed in the following form.

$$Mm = \frac{0.43\ (Mct + Ms)}{7.5} + \frac{0.57\ (Mht + Ms)}{7.5} \qquad \text{Eqn. III}$$

The first term on the right side of the equation is the contribution to the total mass emissions from the cold start portion of the test. The 7.5 in the denominator is the assumed total distance travelled in the cold start phase. It could be replaced by the distance travelled during the cold transient phase, Dct, plus the distance travelled during the stabilized phase, Ds. The second term on the right side of the equation is the contribution to the total mass from the hot start portion of the test. The 7.5 in its denominator is the assumed total distance travelled during the hot start phase. It could be replaced by the distance travelled during the hot transient phase, Dht, plus the distance travelled during the stabilized phase, Ds. If these substitutions are made the equation takes the following form.

$$Mm = 0.43\ \frac{(Mct + Ms)}{(Dct + Ds)} + 0.57\ \frac{(Mht + Ms)}{(Dht + Ds)} \qquad \text{Eqn. IV}$$

If a vehicle were to follow the driving trace exactly, the denominators in both terms would equal 7.5 miles and Eqn. IV would be equivalent to the one currently used in the Federal Register.

The Highway Fuel Economy Test as described in the Federal Register (5) would also need to be modified to allow for the use of the actual distance travelled in the calculations. This would be accomplished by merely requiring the mass emissions of HC, CO, and CO_2 (in grams) to be divided by the measured distance instead of the nominal 10.242 mi. distance.

References:

1. Letter from J.D. Carpenter to T. Barick, May 29, 1975.

2. Letter from D.A. Hensen to Charles Gray, June 13, 1975.

3. Letter from K. Tomita to Charles Gray, June 19, 1975.

4. Letter from H. Weisbarth to Charles Gray, June 12, 1975.

5. Federal Register, Volume 39, No. 200, "Voluntary Fuel Economy Labeling," October 15, 1974.